Modelling changes in medication use following the introduction of IT-based health policies

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Abstract

Medicines use involves the prescription, transcription, dispensing, administration and monitoring of medicines. These processes are prone to error resulting in the misuse of medicines. Medicines misuse associated with prescription errors and medication administration by the elderly living at home is a growing concern. This problem will worsen with the ageing population, development of new drugs and drug indications, shortage in the general practitioner workforce, poor communication between patients and healthcare providers and poor information management.

Electronic health records could improve the use of medicines by improving access and management of patient and drug information, making work processes more efficient and reducing the workload on general practitioners.

The use of medicines varies under different contexts. Current evaluation methods, such as pilots and trials, fail to capture these differences and changes over time and are inadequate in terms of time, cost, resources and transferability.

This paper will investigate multiscale and multi-method simulation as a tool to describe the use of medicines under different contexts and evaluate alternative health record systems.

Keywords
Multiscale, multi-method, hybrid modelling, system dynamics, agent based, adverse drug events, general practitioners, elderly, electronic health records, personal health records

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Problem Description

The use of medicines is a system that involves the prescription of medicines, transcribing this prescription, preparing and dispensing the prescribed medicines by a pharmacist, administration of the medicine and monitoring of the patient for therapeutic or adverse effects by a nurse, carer or self (Institute of Medicine 2006 p.60).

Multiple factors in the health system make these processes prone to error and encourage improper use of medicines. They subsequently cause adverse drug events, any injury (preventable or non preventable) due to medication (Bates et al 1995). Factors include errors in judgement, failure to recognise signs and symptoms, poor communication between patients, multiple health providers and the prescriber, inadequate patient assessments and poor patient follow up (Bhasale et al 1998). Incidents arising from inappropriate drugs, prescribing and administration errors (Bhasale et al 1998) were most common. Dispensing errors occurred in 10% of medication incidents (Bhasale et al 1998).

In a six month period, Miller et al (2006) estimate 10.4% of Australian general practice patients experience an adverse drug event. Of these encounters, 8% result in hospitalisation (Miller et al 2006) and account for 2.4% – 3.6% of all hospital admissions (Roughhead et al 1998).

The misuse of medicines is a growing concern particularly for the elderly living in the community. The elderly are the main consumers of prescription drugs with 86% of Australians aged 65 and over using prescribed medicines compared with 59% for the general population (Australian Institute of Health and Welfare 2002). The elderly are thus more exposed to the medicines use system and it's flaws. The use of multiple drugs (polypharmacy) and the effects of ageing on the mental and physical ability to manage drugs further contribute to improper medicines use such as poor medication compliance, and the occurrence of adverse drug events. The rate of adverse drug related presentations to the general practitioner peaks in those aged 65 and over (Miller et al 2006) and account for 30% of all unplanned hospital admissions for people aged 70 and over (Runciman et al 2003).

It is estimated that 43% of adverse drug events are preventable (Department of Health and Ageing 2002). This paper will describe how processes in medicines use could be improved to help control the incidence of preventable adverse drug events.

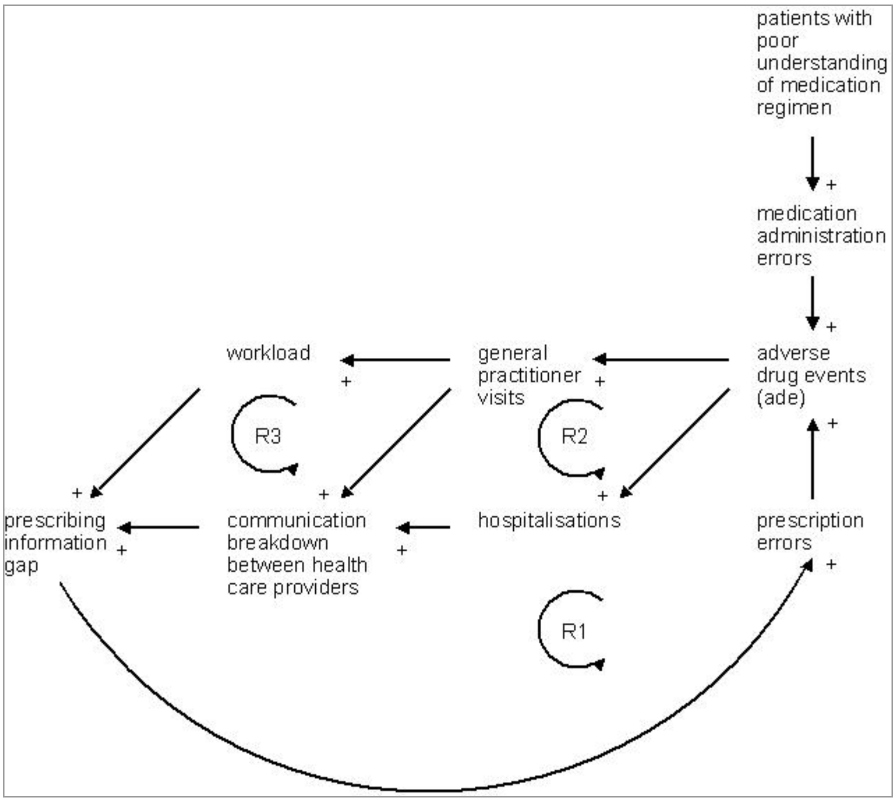

Figure 1. Improper medicines use.

Figure 1 shows a causal diagram that describes how improper medicines use causes adverse drug events and the management of these events. Administration and prescription errors are shown as they are the leading causes of medicine incidents. For the elderly living at home, preventable medication administration errors depend on their understanding of their medication regimen. Non preventable causes for medication administration errors such as the physical and mental inability to self medicate will not be discussed in this paper.

Inappropriate medicines can be prescribed to patients due to a number of factors. These include insufficient patient information, poor communication of patient history or medication changes between the patient, other health service providers and the prescriber or information for new drugs are incomplete. For example adverse drug reactions to a new drug, unintended and non preventable harm caused by a reaction to a drug (IOM 2006), are continually being discovered after the drug is available on the market.

Administration and prescription errors cause adverse drug events at home. Depending on the severity of these events, treatment can be sought from the general practitioner or the person can be admitted to the emergency department in hospital. Once the treatment is completed, the health providers should exchange information about this encounter (including changes to the medication regimen). Currently, this process is inadequate with 45% of general practitioners not providing medication information to hospitals and 63%

of general practitioners not receiving discharge information (including reasons for changing medications) from hospitals (Mant et al 2002). Inadequate communication between health providers form part of the reinforcing loops R1 and R2. Encounter information, especially changes made to medication regimens, is essential for prescribing and thus preventing prescription related adverse drug events and management of these events.

The misuse of medicines in the community setting will worsen due to a number of contextual factors.

The shortage in the general practitioner workforce is projected to continue (Joyce et al 2006).

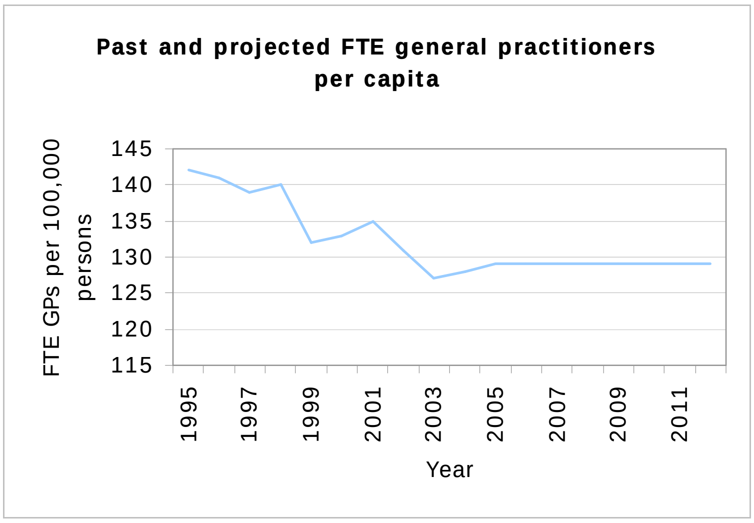

Figure 2. Past and projected full time equivalent (FTE) general practitioners (GPs) per capita (Joyce et al 2006).

This shortage will create a mismatch between the supply and demand for prescriptions. With fewer general practitioners in the workforce, existing general practitioners will face heavier workloads having to consult more patients.

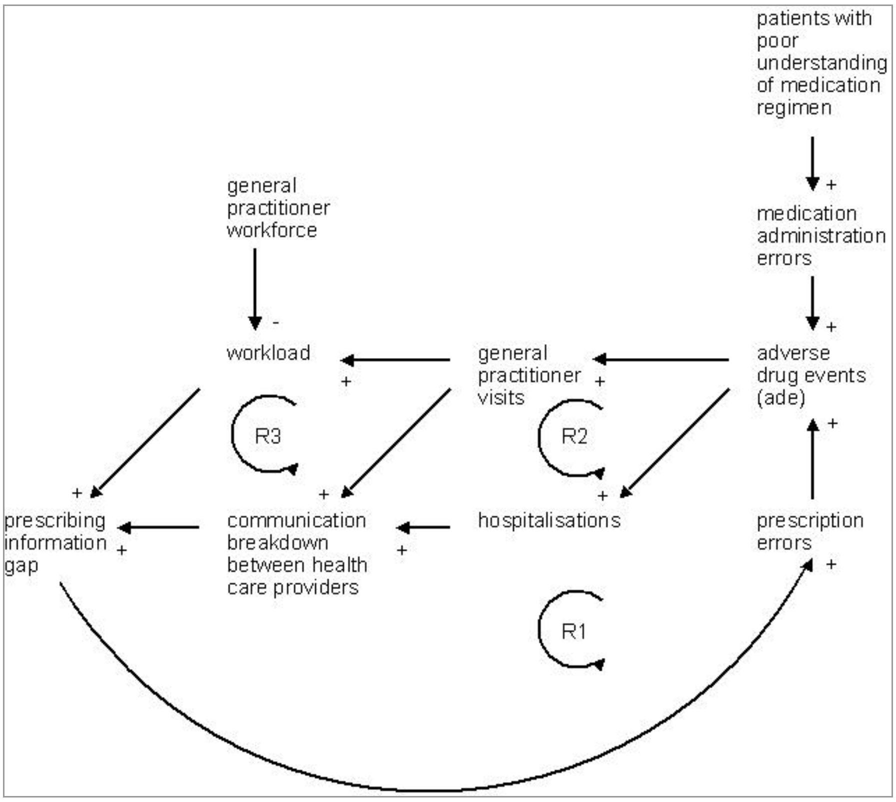

Figure 3. The impact of workload on prescription errors.

Figure 3 is a causal diagram describing the impact of workload on prescription errors. Shorter consultation times can manage this increased workload but limits the opportunity to discuss medications with the patient. Insufficient information increases the chance for prescribing inappropriate medications. A rise in prescription errors will increase adverse drug event related presentations to the general practitioner and further increase the patient workload for the general practitioner. This creates the reinforcing loop R3.

In addition to the general practitioner shortage, the ageing population will contribute to workload pressure.

The elderly aged 65 and over comprise 13% of the population. This proportion is projected to increase to 26% - 28% by 2051 (Australian Bureau of Statistics, 2006a). The elderly visit the general practitioner more often than the general population and account for 26% of all general practitioner visits (DoHA 2008a). The ageing population will create workload pressure on general practitioners and subsequently increase prescription errors.

Older people consume more medicines as reflected by expenditure on the Pharmaceutical Benefits Scheme. Expenditure per person for those aged 65 and over is 7 times higher than those aged under 65 (Australian Government 2007, p. 102, table C2). The Pharmaceutical Benefits Scheme is a list of drugs subsidised by the Australian government. If the proportion of the elderly population with poor understanding of their medication regimens remains constant, as the elderly population increases, so will the number of medication administration errors at home.

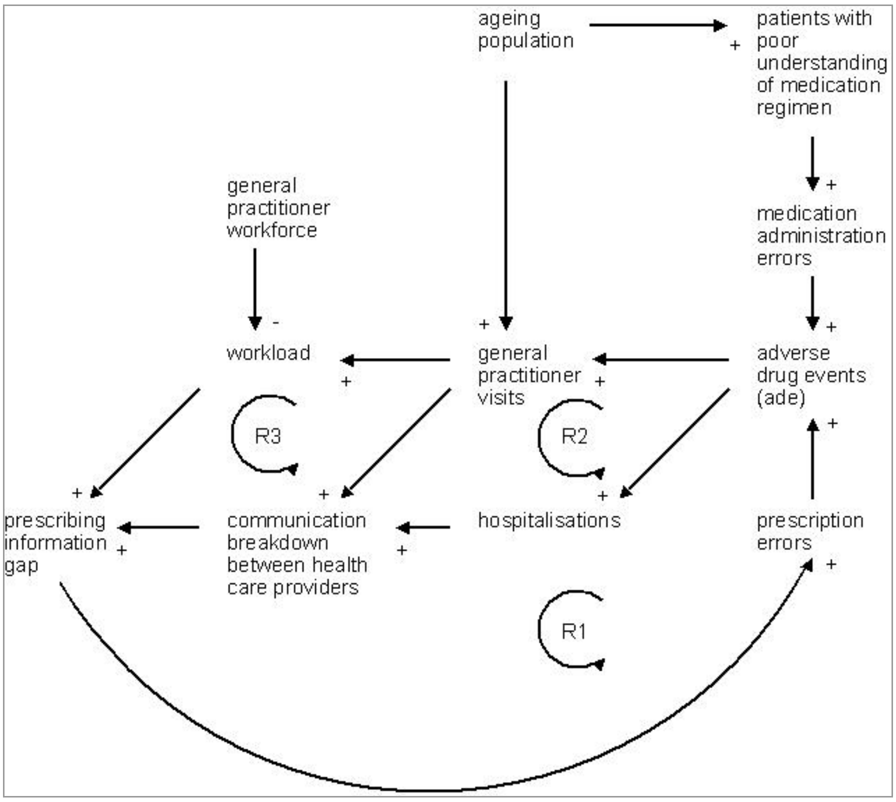

Figure 4. The impact of the ageing population on medicines use.

Finally, the development of new drugs and new uses for existing drugs (drug indications) will influence the use of medicines.

Before a new drug is available on the market, the drug or (new uses for an existing drug) is evaluated for safety (approximately a year), cost and are considered for reimbursement under the Pharmaceutical Benefits Scheme (Therapeutic Goods Administration 2008). Government expenditure on the Pharmaceutical Benefits Scheme has grown significantly at 145% over the past decade (Productivity Commission 2005) despite the small increase in the number of new drugs listed the scheme (DoHA 2008b). The average price of newly listed drugs exceeds that of older drugs (Productivity Commission 2005). This suggests an increase in the prescription of new and more expensive drugs to substitute cheaper drugs or meet medical needs not previously satisfied. This trend of expenditure on pharmaceuticals will be difficult to sustain.

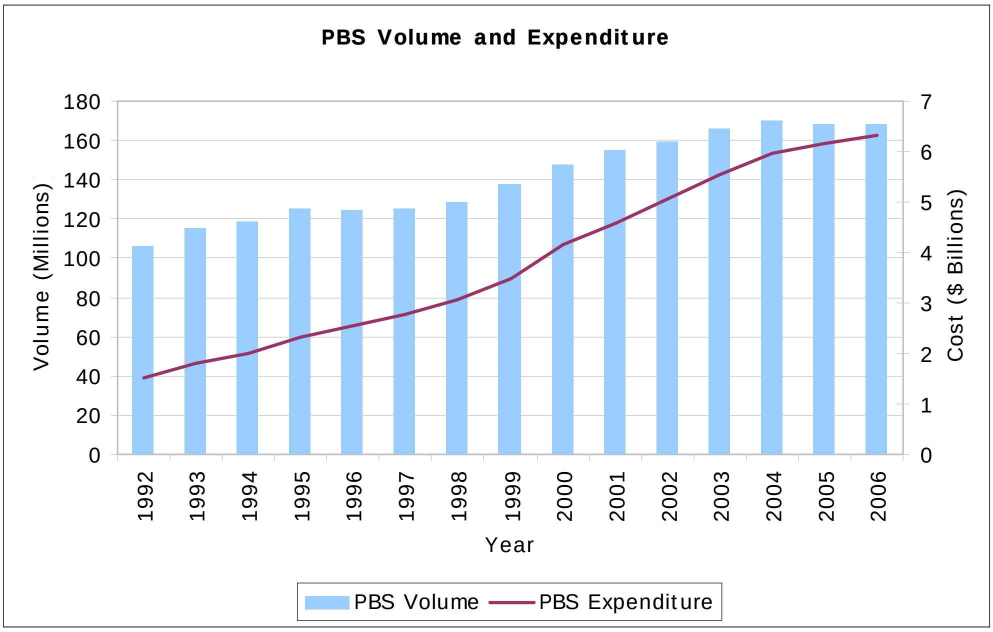

Figure 5. Australian government expenditure on the Pharmaceutical Benefits Scheme and the number of listed drugs dispensed annually (DoHA 2007).

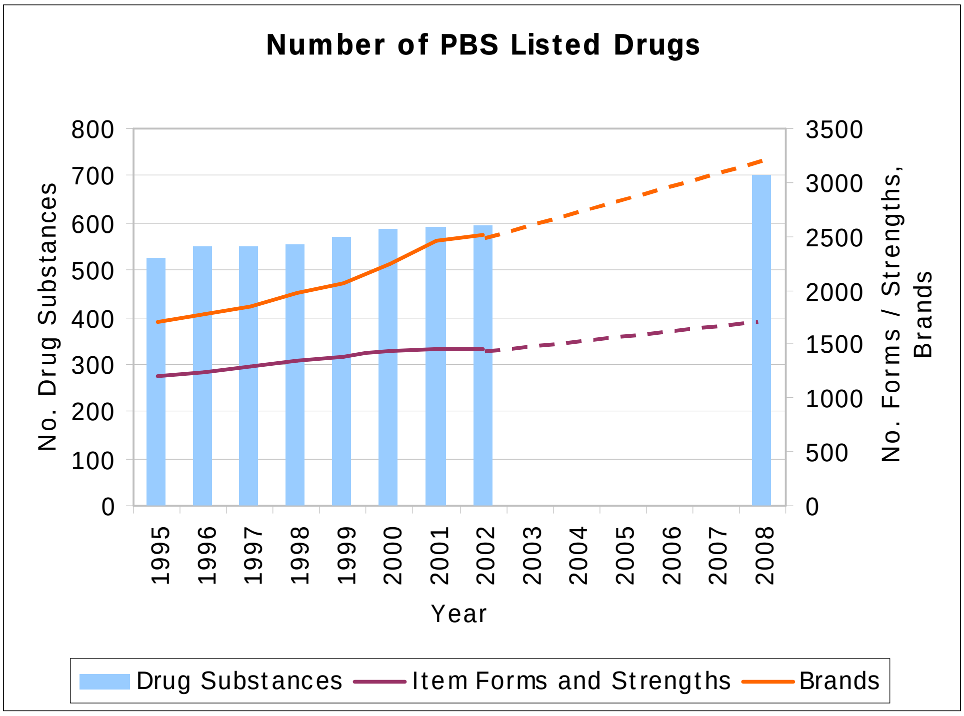

Figure 6. The number of drugs listed on the Australian Pharmaceutical Benefits Scheme (DoHA 2008b) by drug substance (or new chemical entities), item forms, strengths and brands.

Once a new drug is available on the market additional adverse drug reactions are reported. Detection of new adverse drug reactions often occurs after use by a larger population with varying health conditions than those tested in the clinical trial. Delays in receiving adverse drug reaction information could result in the prescription of a drug that causes an adverse drug reaction. Delays in adopting the prescription of new drugs could deny patients of more effective medication treatments. New uses for drugs expand throughout the drug lifecycle (IOM 2006). General practitioners will need to keep abreast with this new information. Figure 7 is a causal diagram that describes the influence new drugs and new purposes for existing drugs have on information required for prescribing.

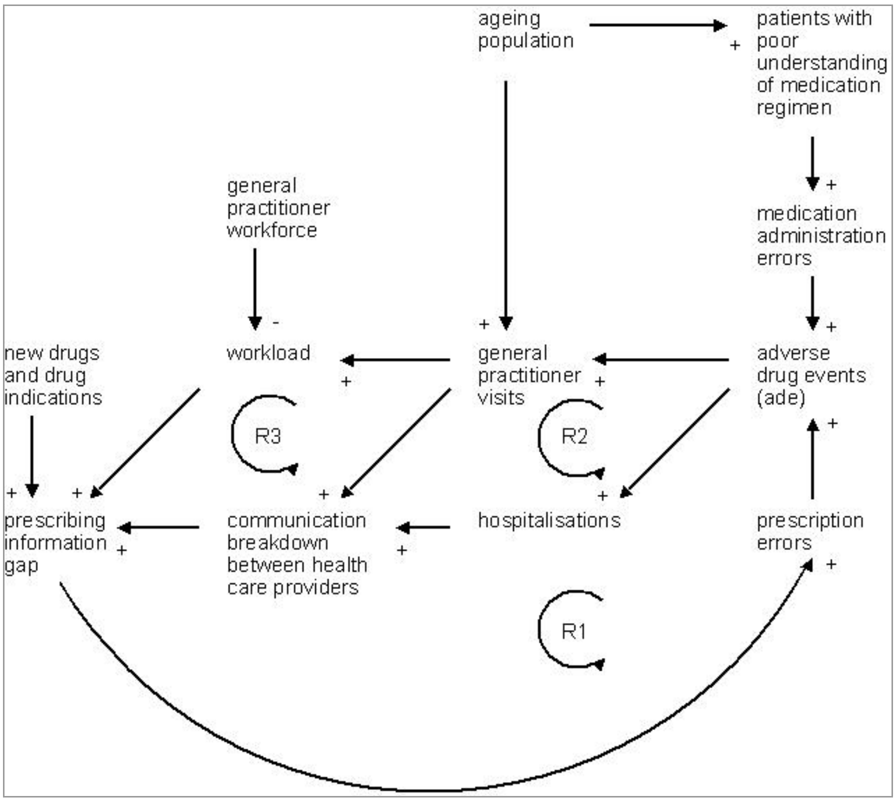

Figure 7. The impact of new drugs and drug indications on medicines use.

Policy Intervention

Information technology, namely shared electronic health records and personal health records is a systems intervention that can improve medicines use.

Electronic health records contain information such as patient details, medication histories, general practitioner and hospital encounter summaries and are stored in an electronic format. There are two main types of electronic health records. Shared electronic health records (SEHR) and personal health records (PHR). Shared electronic health records are stored and maintained by the health service provider for example general practitioners and hospitals. The ‘shared’ feature of these records enables multiple health service providers to access and manage the same records. Personal health records are stored and managed by the patient and brought with the individual to consultations with health service providers.

Shared electronic health records can improve availability, access and exchange of information required throughout the medicines use system. Their benefits for medicines use extend further when integrated with systems such as prescribing support and pharmacy systems. Managing personal health records encourage patients to be more active in their health management, including their medication regimen. Integrating personal health records with health provider systems will enable health providers to have access to patient managed information and could substitute some general practitioner visits. A visit where a repeat prescription is requested could be managed electronically.
An integrated shared electronic and personal health record system is ideal for improving medicines prescription, administration and monitoring tasks. This combined solution encourages patients, carers and health providers to take a more active role and make better decisions when using medicines.

Figure 8 is a causal diagram describing the benefits of an integrated shared electronic and personal health record system. A more active role in personal health management can improve understanding of medication regimens and reducing administration errors. This system can improve communication between hospitals and general practitioners reducing the gap in encounter information required for prescribing and thus reducing prescription errors and finally, reduce the patient workload on general practitioners (and thus prescribing errors) by substituting visits that could managed electronically.

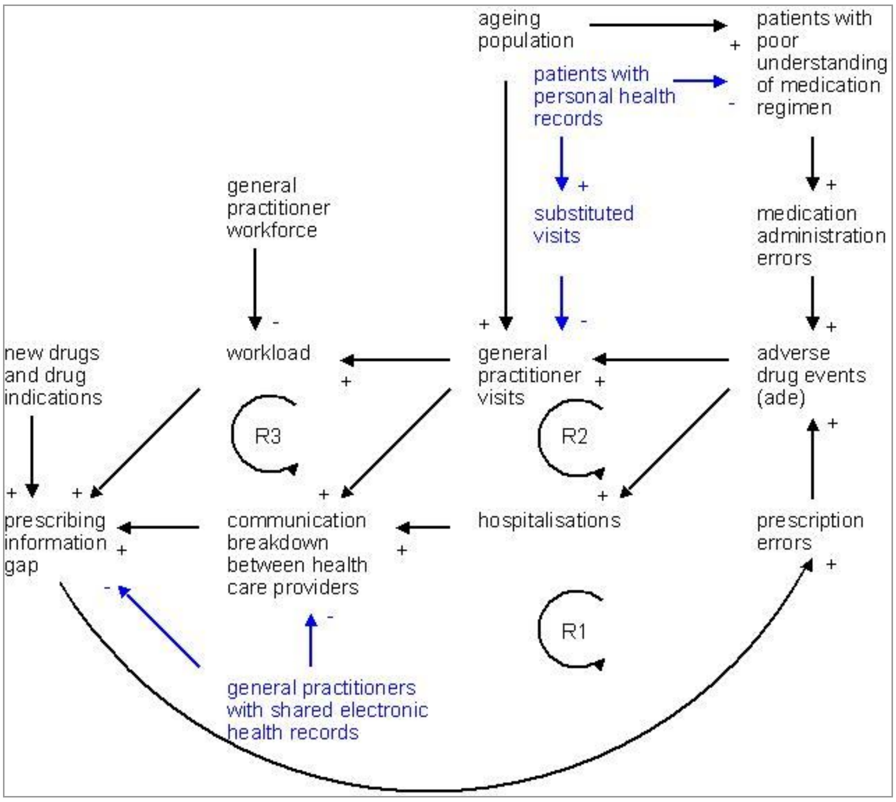

Figure 8. The impact of shared electronic health records and personal health records on medicines use.

The benefits of electronic health record systems for medicines use is currently evaluated with pilots and longitudinal trials. These methods are time consuming, require sample sizes large enough to provide statistical significance, disrupt current working practices, and lack transferability across different settings (Eddy 2007). Policy experiments using computer simulation saves on cost, resources and time and direct recommendations for more appropriate health record systems to be piloted and trialled.

The Model

Systems models traditionally describe a problem at one scale, for example models using aggregate values to generate patterns in system behaviour over a period of years or models that describes interactions between individual objects occurring in seconds or minutes. Medicines use operates over multiple time and population scales. For example, the ageing population and shortage in the general practitioner workforce affect the supply and demand for prescriptions. Ageing of the Australian population of 21 million (ABS 2008) occurs over decades, as does the training of new general practitioners to boost the current general practitioner workforce of 25,000 (DoHA 2008c). Whereas the administration of medicines by a single individual occurs in minutes as does the prescription of medicines to a patient by a general practitioner.

The model presented in this paper extends traditional systems models by describing medicines use across multiple scales in particular, how individuals use medicines under different contexts.

System Dynamics is used to model the context of medicines use. System Dynamics makes explicit key structures and aggregate patterns in behaviour that drive medicines use. It identifies, reinforcing and balancing feedback loops and delayed responses (Sterman 2000). System Dynamics is used to describe how the ageing population, shortages in the general practitioner workforce, drug advances and health record system deployment change over a period of decades.

Agent based modelling is used to model daily uses of medicines by the elderly and general practitioners under these contexts and how these behaviours change as the context changes. Agent based models comprise autonomous agents or individuals with defined characteristics and rules for interacting with each other and the environment. Emergent behaviour arises from repetitive and cooperative interactions between agents and their environment (Bonabeau 2002; Axelrod and Tesfatsion 2008).

The integration of these models produces a multiscale model of medicines use. During simulation of the model, the scale can be changed in real time (Bassingthwaighte 2006). It can show the balance between the impact of context and collective individual behaviour on medicines use and cross-scale effects (Villa 2001) such as the effect of context on individual behaviour or how these behaviours collectively influence the context. For example, the deployment schedule of shared electronic health record systems determines the proportion of general practitioners and hospitals that can use these records. With larger coverage, more information is available for a general practitioner to use when prescribing medicines reducing the chance of prescribing errors. However, even with health record technology implemented across the population adoption can limit the improvements these systems have on medicines use.

This multiscale model is useful for understanding the extent to which large scale policies affect the behaviours of individuals. In particular, how health record systems, along with the ageing population, general practitioner workforce shortages and drug advances, affect the way people take their medicines and how general practitioners prescribe medicines. In addition to observing individual behaviour, interactions between individuals can be analysed. For example, how the use of medicines differs between elderly patients who use a personal health record and see general practitioners with shared electronic health records versus those who do not have personal health records or see practitioners without shared electronic health records.

Elderly Patient	**General Practitioner**
No personal health record	No shared electronic health record
No personal health record	Shared electronic health record
Personal health record	No shared electronic health record
Personal health record	Shared electronic health record

Table 1. Possible combinations of elderly patient – general practitioner health records.

Collective behaviours of these individuals provide an overview of medication administration and prescribing error rates and government expenditure on medicines use. These expenditures include the Pharmaceutical Benefits Scheme and the Medicare Benefits Schedule, a universal public health insurance scheme that subsidies for the cost of bulk billed general practitioner consultations and public hospital admissions. This analysis is useful for evaluating alternative health record systems and directing appropriate health record pilot studies.

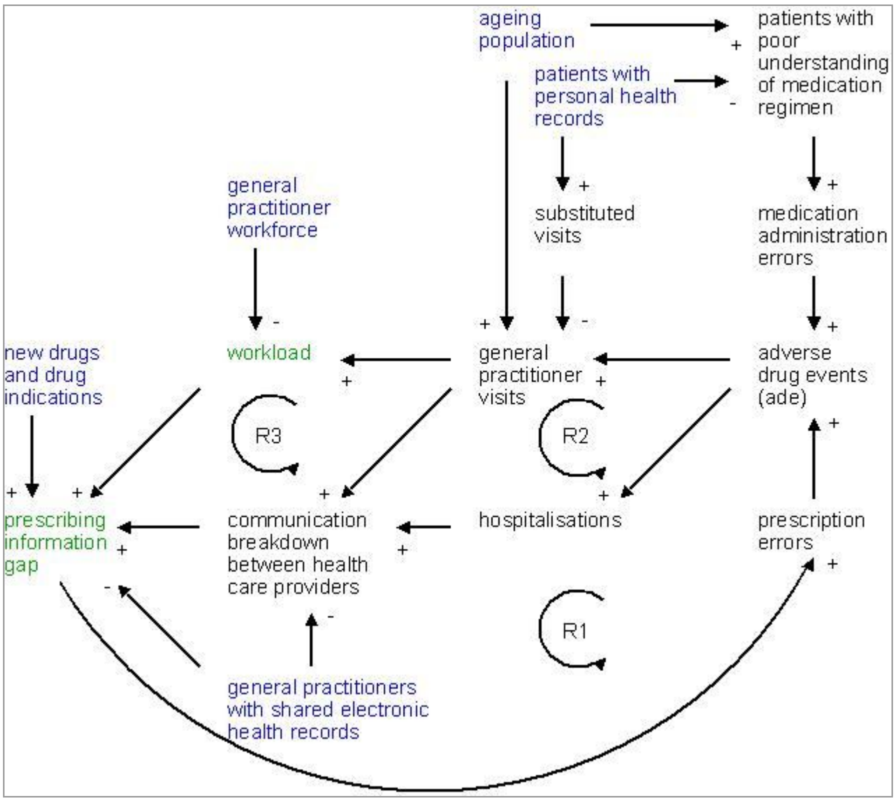

Figure 9. The context and individual behaviours captured in the model.

Figure 9 highlights context components of medicines use modelled with System Dynamics (blue) and individual behaviours modelled with the agent based method (black). It also highlights factors that are calculated by integrating elements from the System Dynamics model and the agent based model (green). Anylogic6 is the modelling and simulation package used to develop this model. It can build and integrate System Dynamics and agent based models. Anylogic6 can produce portable simulations that are accessible through a web browser (XJ Technologies 2008).

The components of the model will be discussed in more detail.

<u>The Context</u>

The ageing population is based on the Australian Bureau of Statistics 2006b population projection model. In this model assumptions made about future levels of fertility, mortality, overseas migration and internal migration are applied to a base population (split by sex and single year of age) to obtain a projected population for the following year. This process is repeated to project subsequent years (ABS 2006b). These projections span the period June 2004 to June 2024.

The general practitioner workforce model is based on Joyce's 2006 medical workforce model. In this model, new graduates, immigrants and re-entrants to the workforce are added to the base general practitioner workforce (split by sex and age), and deaths, retirements and attrition exits are subtracted for each year. Adjustments are made for movement between occupations within the medical workforce and for ageing. This obtains a projected number of general practitioners in the medical workforce for the next year and repeated for subsequent years (Joyce 2006).

The model of the development of new drugs and availability on the Pharmaceutical Benefits Scheme is based on the drug supply, listing and pricing components of Heffernan et al 2004 National Medicines Use System Dynamics model. New drugs enter the market. Some are listed on the Pharmaceutical Benefits Schedule. These drugs go through the process of being listed as the first drug of its kind, a premium brand or a generic brand before being removed off the list. The drug is priced accordingly with the average drug price increasing with inflation. The proportions of drugs used amongst these classes' influences expenditure by the Australian government subsidising these drugs.

The model of the health record system is configured by the user through the user interface of the simulation. The user, typically a policy analyst, sets the development, deployment and adoption rates, start up and per-unit costs and effectiveness of shared electronic health records and personal health records on prescription and medication administration errors respectively. Factors such as time allocated to a health record system project, budget and the health and cost benefits desired from the project will influence the configuration settings.

The Individuals

Elderly patient "agents" and general practitioner agents are defined in the individual-based model.

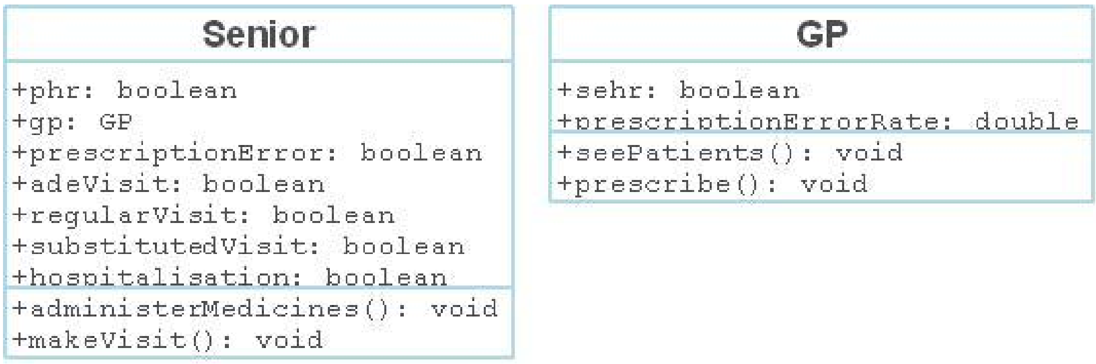

Figure 10. UML Class diagram of the Senior and GP agent.

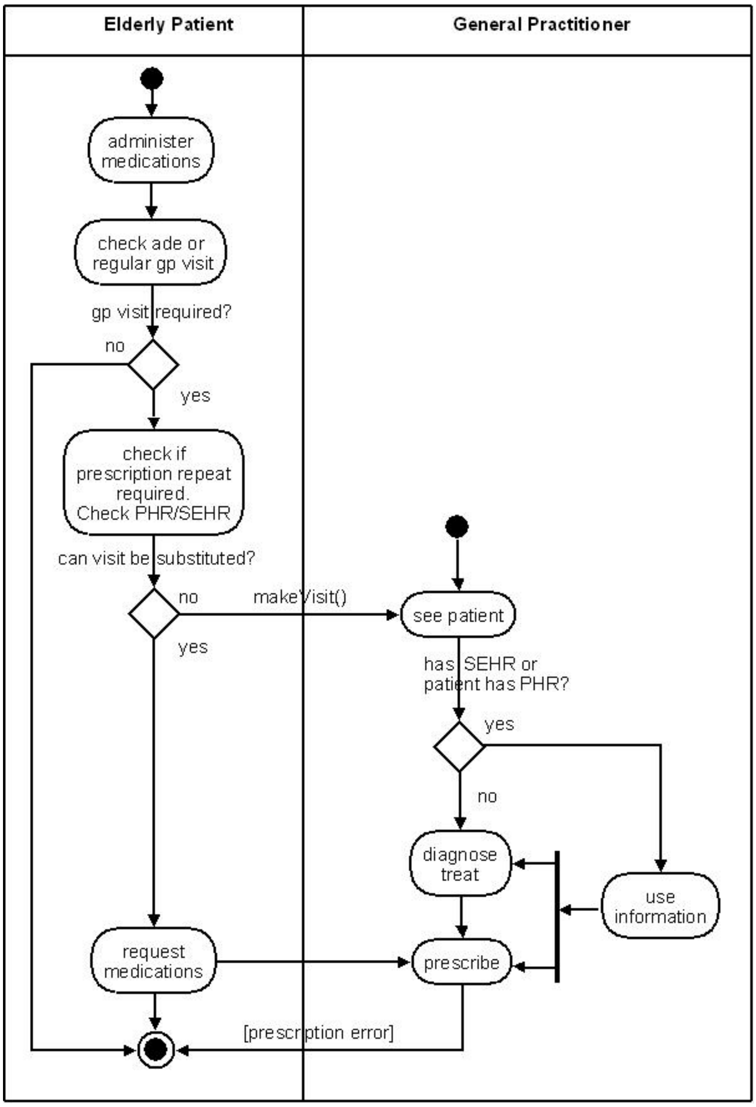

Figure 11. UML Activity Diagram of a patient administering medicines, visiting a general practitioner and a general practitioner seeing and treating patients.

Figure 10 shows the attributes and rules each elderly patient agent and general practitioner use and follow when interacting with other. For example, the visit flags (adeVisit, regularVisit) are used to determine whether the elderly patient will see the general practitioner that day.

Figure 11 is a UML activity diagram that describes the core activity of medicines use, administration of medicines by an elderly patient, prescribing of medicines by general practitioners and the interaction between the patient and general practitioner in a consultation.

Each elderly patient administers medicines daily. An adverse drug event can occur if medicines are taken incorrectly or inappropriately prescribed medicines are consumed. If the patient has a personal health record, the chance of administering medicines incorrectly is reduced (by an amount provided by the simulation user through the user interface). A patient will visit a general practitioner if they have experienced an adverse drug event or are due for a regular visit (determined by the average general practitioner visit rate). Serious adverse drug events result in hospitalisation (not shown in the diagram). A general practitioner visit requesting a prescription repeat can be substituted with an electronic request provided the elderly patient has a personal health record that is linked to his or her general practitioner’s shared electronic health record system. Otherwise, the patient will visit the general practitioner. The general practitioner will see patients on his or her waiting list. If the general practitioner has access to shared electronic health records or the patient’s personal health record, this information will be used to help diagnose, treat and if required, prescribe medications. Inappropriate medicines can be prescribed if the general practitioner has insufficient information or has a heavy patient workload.

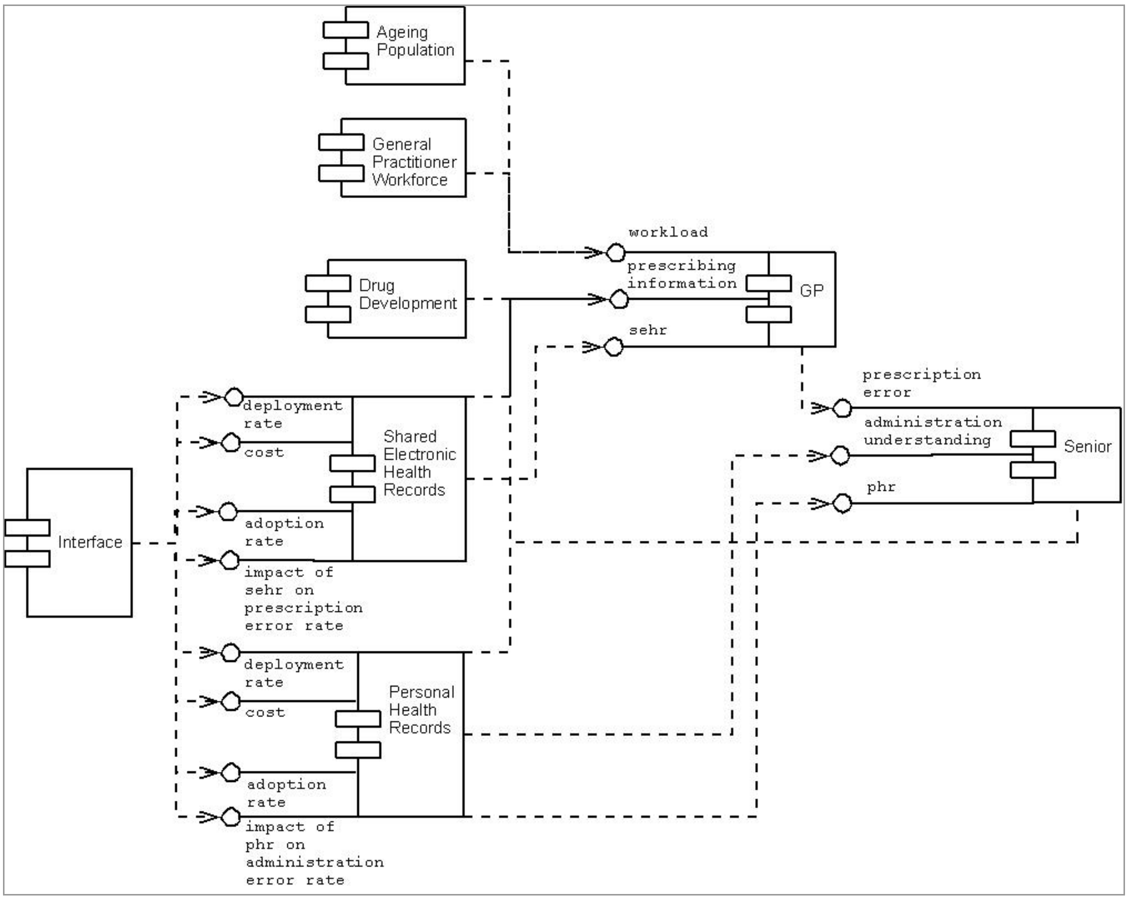

Figure 12. UML Component Diagram of the medicines use model

Figure 12 provides an overview of how the interface, context level of the model and individual agents are linked. It shows information passed between components of the medicines use model.

Conclusion

Improper medicines use results in many preventable adverse drug events, particularly with the elderly living at home. This situation will worsen with the ageing population, drugs advances, shortage in the general practitioner workforce and poor information management and exchange between the patient, health providers and the prescriber. Shared electronic health records and personal health records could bridge the information gap and reduce work pressure on general practitioners. Current evaluation methods are in inadequate in terms of time, cost, resources and transferability. Multiscale, multi-method simulation is useful for describing how individuals use medicines under changing contexts and alternative health record systems. This provides a tool to aid health record system evaluation and direct better health information technology policies.

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